Simultaneous Rotational Analysis of Complex Multi-Spot Sunspot Groups

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Sunspot Rotations

Sunspots have long been associated with flaring and CME activity on the Sun, and a significant number of sunspots that are associated with flares also exhibit a rotation about their axis, about one another, or some combination of the two [Yan *et al* (2008)]. Typically, a sunspot's rotation is measured by fitting an ellipse to the umbral/penumbral boundary and calculating the inclination angle of the major axis against a baseline. This process is usually applied to the entirety of a spot, or painstakingly to a sub region that has to be manually identified and separated from the rest of the spot. Even then this technique frequently encounters problems as sunspots decay or merge as they evolve. Fig 1. illustrates the difficulties that can be encountered when trying to form a contour around a decaying sunspot that has begun to form striations in the umbra. The contour lines become erratic and unstable as the radial intensity gradient from the darkest point becomes non-linear, making a meaningful ellipse fit on these contour lines difficult. Whilst in this case it would be possible to interpolate between the edges of the striations in the umbra, it would seem more reasonable to treat them as individual features in their own right – particularly when dealing with the general case.

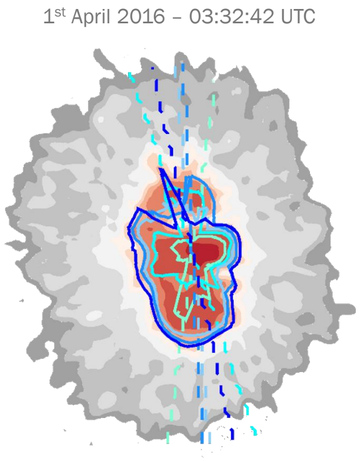
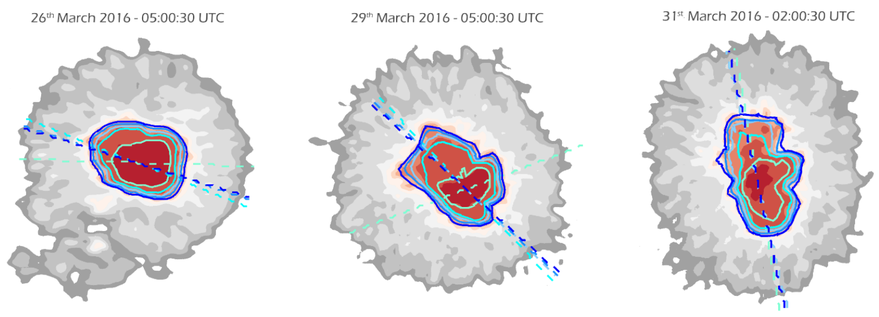


Fig 1. Contour plots of the sunspot in NOAA 12526. Solid blue lines indicate the edges of the contour at a given intensity. The dashed lines indicate the major axis of the best fit ellipse. The image on the left is from the decay phase of the spot where this technique breaks down.



Unusual Motion of NOAA12158

NOAA 12158 was an active region on the Sun between the 5th and 14th of September 2014 that produced a large X1.6 flare near the solar limb. On the photosphere below this active region was a group of sunspots as shown in Figs 3,4. [Bi et al (2016)] showed that during the time of this flare a southern region of the spot appeared to rotate counter to the direction of the rest of the spot - and the direction it had previously been rotating. This unusual partial rotation is a primary target and ideal case for analysis by the technique presented here.

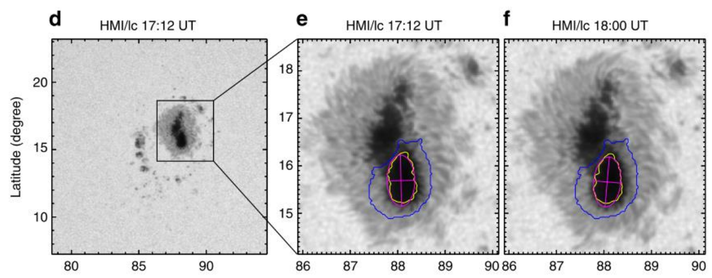
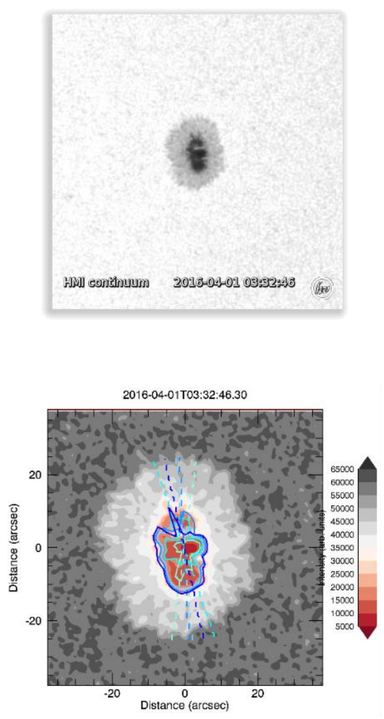


Fig 3. Figure 1 from Bi *et al* (2016) showing NOAA 12158 and the subregion exhibiting the unusual rotation.



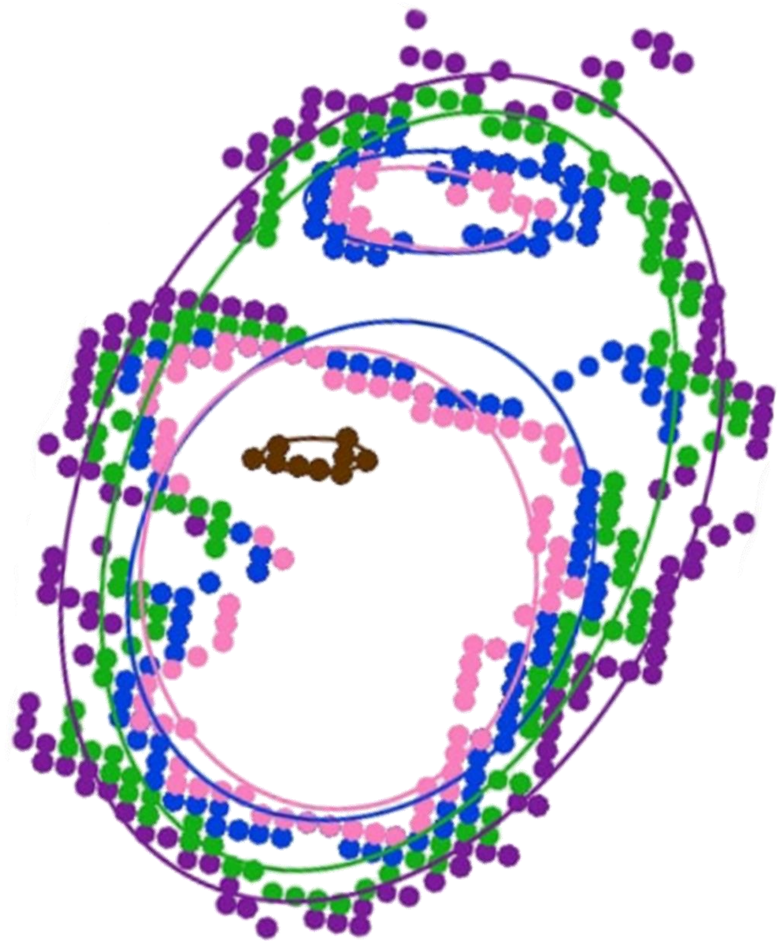


Fig 2. The figure on the upper right shows this technique being applied to the decaying sunspot NOAA 12526 (shown in HMI continuum and a contour plot in the upper left). The colour of the dots indicates intensity, brown being darkest and purple lightest.

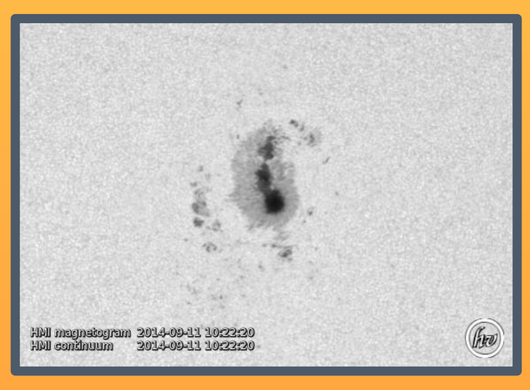
A Solution in OPTICS

An approach was devised that uses multiple levels of image thresholding and the OPTICS clustering algorithm to distinguish features within the umbrae of sunspots, and can be further scaled to be applied to entire sunspot groups. The method applies a threshold to a given image of a sunspot or group and then clusters all the pixels below the threshold together using the OPTICS clustering algorithm. OPTICS is a density-based clustering algorithm (similar to DBSCAN) that uses reachability plots to determine clusters without the need to know how many are required beforehand. When these clusters are found, rotational data can be extracted by ellipse fitting. The process then iterates with the next level of thresholding. Applying this technique to the spot in Fig 1 gives the diagram shown in Fig 2. It can be seen from the blue and pink contours that at the lower intensities the umbra has split into separate sub-umbral groups which can be tracked individually from the global rotation.

Next Steps

The intensity clustering technique developed here has been shown to work on a single decaying sunspot but the next step of this project is to apply the technique to an entire sunspot group. The sunspot identified in [Bi et al (2016)] is a good target for this due to its relatively simple configuration and the mystery surrounding its unusual rotation. Successful completion of this step would open the doors to investigating any number of increasingly complex groups.

Fig 4. This is another image of NOAA 12158 accessed via helioviewer. This image shows the full extent of the sunspot and its group neighbours, the simultaneous analysis of each element of which is the next project goal.



References

1. Bi, Y., Jiang, Y., Yang, J., Hong, J., Li, H., Yang, B., & Xu, Z. (2016). Observation of a reversal of rotation in a sunspot during a solar flare. Nature Communications, 7. https://doi.org/10.1038/ncomms13798
2. Yan, X.-L., Qu, Z.-Q., & Kong, D.-F. (2008). Relationship between rotating sunspots and flare productivity. Monthly Notices of the Royal Astronomical Society, 391(4), 1887–1892. https://doi.org/10.1111/j.1365-2966.2008.14002.x

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